E/CONF.39/A/132
17 Oct.1962
ORIGINAL : ENGLISH

UNITED NATIONS CONFERENCE
ON THE APPLICATION OF SCIENCE AND TECHNOLOGY
FOR THE BENEFIT OF THE LESS DEVELOPED AREAS

Agenda Item: A.3.3

Israel

CONTRIBUTION OF ISOTOPE METHODS TO HYDROLOGICAL RESEARCH

By J GAT
and A. NIR,
Weizmann Institute of Science,
Rehovoth Y. Harpaz and S. Mandel,
Tahal, Water Planning for Israel Ltd.

Papers have been contributed to the United Nations Conference on the Application of Science and Technology for the Benefit of the Less Developed Areas as working papers for that Conference. They are published as presented by the contributors, and the contents and the views expressed are those of the contributors. (See notes overleaf.)

NOTES

1. Papers selected for inclusion in General Sessions will be available at the Conference in the following official languages of the United Nations: English, French, Russian and Spanish.

2. Papers selected for inclusion in Specialized Sessions will be available at the Conference in only one of the above official languages.

3. Summaries of all papers, as submitted by contributors, will be available at the Conference in the following official languages of the United Nations: English, French, Russian and Spanish.

4. Papers and summaries will not be available for general distribution in advance of the Conference. They will be published in advance in limited quantities only for the use of delegations of participating governments and of other authorized participants. Post-Conference publication and general distribution of the Conference Proceedings will follow United Nations practices as laid down by the United Nations Publications Board.

Contribution of Isotope Methods to Hydrological Research

by

J.Gat and A.Nir, Weizmann Institute of Science, Rehovoth
Y.Harpaz and S.Mandel, Tahal, Water Planning for Israel Ltd.

Hydrological investigations of groundwater usually follow a well defined pattern which is conditioned by the state of development of the research region. It is convenient to distinguish three phases of development:

(1) Only "natural" water resources such as rivers, springs, etc. are used.

(2) Groundwater is extracted from boreholes and used alone or in addition to natural resources.

(3) All occurrences of water are fully used not only for supply but also for storage, disposal of sewage, etc.

This summary intends to follow the natural pattern of development and to indicate the contribution of isotope methods towards the solution of problems peculiar to each stage. It may be stated in advance that isotope methods represent only an additional research tool but by no means the panacea for hydrological problems.

1. When water supply in a region is based on the natural flow of springs and rivers only, the reliability, constancy and hydrological characteristics of the flow must be investigated. Classical methods of investigation are: geological reconnaissance,

geo-chemical analyses and statistical analysis of the hydrograph (especially determination of the decay-curve). Knowledge of the time elapsed between natural replenishment and reappearance of the groundwater and the size of the intervening reservoir are the significant hydrological parameters.

2. When one or a few wells are drilled in a new region, it is important to determine as quickly as possible, the ultimate "safe yield" of the region, including changes of the water level to be expected during continual exploitation. In this context it is necessary to find out in what way natural drainage of the groundwater is affected. If the aquifer is drained by springs and its exploitation will eventually reduce springs flow, this factor must be taken into account when regional schemes of development are envisaged. If swamps represent the natural outlet of the groundwater, heavy pumpage may help in draining the area and this not only provides water but also arable soil. If groundwater drains into the sea, the effects of the sea water intrusion must be evaluated.

The physical parameters involved in the problems are:

1) Is the water located in a borehole identical with the water issuing at the point of drainage?
2) The physical constants of the aquifer: transmissivity, storability effective porosity.
3) Velocity of groundwater flow.
4) Dimensions of the aquifer.

The classical methods of research rely on pumping tests and precise measurement of the gradient of the piezometric level and necessitate pumping wells and a number of observation holes, all of which must be interconnected by precise levelling and measurement continued for extended periods of time. The demonstrated and potential usefulness of the isotope tracers in supplying information on these

parameters is therefore of primary importance.

3. Scientific management of groundwater resources. In a fully developed region the natural occurrences of water are fully integrated in engineering works. This presupposes a very detailed quantitative knowledge of all the properties, e. g. natural replenishment, its fluctuations and its mechanism, reserves which may be used to tide over dry cycles, connection with sea water and highly mineralized bodies of water. In addition parts of the aquifer will not only be used as water resource but also as storage reservoir (artificial replenishment) cleaning plant (re-cycling of sewage water) and waste disposal unit.

In an arid region where water is scarce this last stage of development may be arrived at very quickly and it is therefore important to start collection of the necessary quantitative data well in advance. This task can be very much eased with the aid of isotope methods, as there are no classical reliable methods for evaluation of dispersion and mixing patterns of different bodies of water.

II. The Isotopic Tracing Methods

The isotope tracing methods described in this paragraph were applied to the solution of the various hydrological problems previously presented. It should be mentioned, however, that tracing with isotopes was applied as an integral part of the tracing method in general, and other means of labelling and tracing, i.e. chloride or fluoresceine, were used whenever the use was considered to be of advantage compared to isotope methods.

The basic principles and methods of application of the isotope tracing methods were surveyed in several publications(1,2,3,4). It will suffice therefore to give the general classification of these methods.

The tracing method in hydrology is based on observing some identifiable component of the groundwater body, which is assumed to behave in all relevant hydrological aspects similarly enough to the main body of water which is being observed.

We can distinguish between 4 different processes, which provide us with measurable tracers for groundwater.

1. Natural introduction of radioactive isotopes:

Examples of these are cosmic radiation produced tritium and C^{14}. Others are radioactive daughters of the uranium and thorium which are leached out of the rock by groundwater. Natural tritium for example, can be used as a "dating" tool. For sources which did not receive replenishment from meteoric waters, since the commencement of the thermonuclear explosions (1952) the significant value is the

comparison of the tritium concentration of the observed aquifer, with the average activity of rain water assumed to feed this aquifer. Where necessary the latter is corrected for isotopic fractionation, due to partial evaporation of the rain waters, before reaching the aquifer. This difference can then be interpreted as due to transit time in a non-mixed aquifer, an average hold up time in a mixed reservoir or an intermediate value between those, depending on the specific assumptions about the flow pattern.

2. Introduction through nuclear explosions:

Various isotopes are introduced through nuclear explosions of atomic weapons and operation of nuclear reactors. Of these again only tritium is considered an effective tracer of groundwater. Due to recent origin of these sources, its application has to be limited to problems on the corresponding time scale, i.e. 9 years. Although controlled by man, this type of injection is considered from the point of view of hydrological investigation as rather closer in character to the natural introduction, as there is no control by the experimenter on the time, extent and amount of injection, which is mostly very widespread.

In using this method, the time distribution of groundwater concentrations (the output pulse shape) is correlated with the rain water concentrations (the input pulse shape). This relation is interpreted in terms of transit time distribution of the rain waters feeding the area. If used in conjunction with the geological information on the extent of local aquifers, they provide data on the replenishment rate of the groundwater reservoir.

3. Local, controlled injection:

Suitable isotopes can be injected locally under conditions most suitable for the specific problem to be solved. Due to the limitations imposed by health hazard regulations, these activities are usually limited in scale and extent to relatively small areas and short periods of time. At present the injection method is limited to limestone and sand aquifers, due to possible adsorption effects in other types of soil. A common tracer used locally is $K_3Co(CN)_6$ incorporating Co^{60} or Co^{58} as the radioisotope. Other tracers like I^{131}, S^{35} have been used occasionally (5,6). Tritium which is often recommended as suitable for local injection is not used here, as it is considered to endanger the investigations utilizing the rain recharged tritium. These isotopes can be conveniently used for investigation of local groundwater velocities, storativity and mixing patterns in recharge operation.

4. Stable isotopes:

Differences in natural abundances of D and O-18 caused by physico-chemical

differentiation processes in the atmosphere, during evaporation of surface water bodies or through exchange of isotopes with rock components, singularly characterize different water bodies and hence can be utilized as tracing tools in hydrology. Of even greater significance in hydrological research is the fact that the measured changes of O^{18} and D abundances as a result of evaporation from surface water can be interpreted in terms of the amount of evaporation.

Stable isotope difference can be therefore useful in identifying origin of groundwater or mixing ratios in case of converging sources. In favourable cases of widely differing components, dispersion pattern in recharge can be investigated.

III. Applications

Several examples of planned and executed applications of the isotope tracing method in Israel will serve to illustrate typical contribution of this method to a semi arid zone hydrological research.

1. Tritium survey:

A wide sampling program of local rains, wells springs and surface reservoirs is carried out since 1953. These are examined for tritium, O^{18} and D. concentrations. This extensive isotopic mapping is expected to lead to a coherent picture of the country wide hydrological cycle when several years data are assayed and evaluated. Up to date several years rains and few well samples were measured. The rain data, being themselves of meteorological interest (7) serve as input function for the groundwater transit time distribution study. By this method we could deduce recent recharge for some arid area wells. The sampling program was recently extended to include depth sampling in wells in order to study the vertical velocity distribution in aquifers.

2. Injection experiments:

These experiments have been carried out since 1957 and provided locally significant data. Some experiments, using I^{131} and later Co^{60} in the form of $K_3Co(CN)_6$, were devoted to storativity determinations (8, 9) and gave results consistent with those obtained by other hydrological methods. Other experiments were made to determine ground water velocity using the single well method (10) and to determine the character of the interconnection between the Lod aquifer and the Yarkon river. Presently planned experiments are concerned with dilution of high salinity water by recharge into existing aquifers.

3. Stable isotopes:

A countrywide survey of the O^{18} and D concentration is carried out in parallel

with the tritium survey. Significant variations are evident along the Jordan river basin indicating the effect of evaporation. While actual application can not be undertaken before continued measurements confirm the significance of this pattern, the visualised applications include mixing studies during recharge of Jordan river water into groundwater aquifers, assistance in tritium transit time determination through identification of corresponding water bodies, and general differentiation between groundwaters of different origin.

IV. Organization

The discussion of organization and procedures required for this type of project is of considerable interest. The main points to be considered are: cooperation, technical personnel facilities and equipment and budget.

1) Cooperation:

As this subject is common to hydrologists and nuclear scientists, the requirements for close cooperation is obvious. It was found, however, that significant results require definite efforts and procedures. These are:

a) some understanding of the basic principles and methods of the other discipline, gradually progressing to common study of the subjects.

b) closest contact in all stages of work: preliminary studies, planning of the experiments, execution and evaluation. Mixed teams in field experiments are of value in early stages of the project.

c) cooperation of health authorities and water supply organization is essential for successful execution of experiments based on the injection method.

2) Technical personnel:

Nuclear scientists experienced in low level counting techniques are essential for cooperation of the above projects. For continued operation one full time scientist is required for each of the distinct methods, i.e. tritium, injection and stable isotopes. However, not all of those measurements have to be performed locally, as discussed below.

3) Facilities and equipment:

Low level isotopic measurements require equipment and facilities which although not too complicated, are quite specialized and as yet not available commercially. In fact no single laboratory is known to perform routinely all the measurements previously discussed. The tritium assay requires an isotopic enrichment plant and very low level radioactivity counting and handling systems. The stable isotope measurement is performed with very sensitive mass spectrometers. Both require laboratories free from mechanical and electrical disturbances and capable of providing good

electronic maintenance service.

The injection method requirements are less stringent, but reliable field instrumentation, a standard radioactivity counting laboratory and high activity handling facilities are required. However, it is feasible to carry out a fair amount of this type of work in cooperation with other laboratories which specialize in tritium or stable isotope assay. International cooperation is already contributing to this subject in countries lacking own facilities.

4. Budget:

Although a detailed budget will very much depend on the facilities available and the capabilities of the personnel to provide own equipment a general estimate may be given. The initial investment in scientific equipment in an existing laboratory, for a full scale program: i.e. 300 tritium samples per year, 500 D and O^{18} samples and one field injection set would amount to $ 80,000 while its continued operation including personnel would amount to $ 50,000 per year. This does not include any items normally covered by a hydrological research program such as drilling observation wells, pumping and recharge operations and wide area water sampling. The investment could, however, be considerably reduced through a cooperation program like the one mentioned above.

1. E. Halevy and A. Nir. "On the use of radioisotopes in studies of groundwater flow". Water Planning for Israel Ltd. Publication 32 (1960).
2. Isotopes Inc. "The Potential Application of radioisotope techniques to water resources investigations and utilizations." AEC report NYO-9040 (1961).
3. Report of the panel on the applications of isotope techniques in hydrology. IAEA. 1961.
4. W. Sheppard, "Basic principles of the tracer method", Wiley, 1961.
5. E. Halevy and A. Nir, "Determination of aquifer characteristic with the aid of radioactive tracers." J. Geophysical Res. 67, 2403 (1962).
6. M. F. Merritt, "Routine measurement of groundwater velocity", Health Phys. 8, 185 (1962).
7. J. R. Gat. J. Karfunkel and A. Nir, "Tritium content of rainwater from the Eastern Mediterranean area". Tritium in the Physical and Biological Sciences, IAEA Vienna, p. 41 (1962).
8. A. Nir, E. Halevy, S. Mandel and Y. Harpaz, "Water Planning for Israel Ltd. Publication 32, 1957.
9. A. Nir, et.al. Report No. 4, Water Planning for Israel Ltd. (1961).
10. S. Mandel, "Hydrological field work with radioactive tracers in Israel" I.A.S.H. Commission of Subterranean Waters, Publ. No. 52, 497 (1960).

288 E - Oct.1962 - 1,600